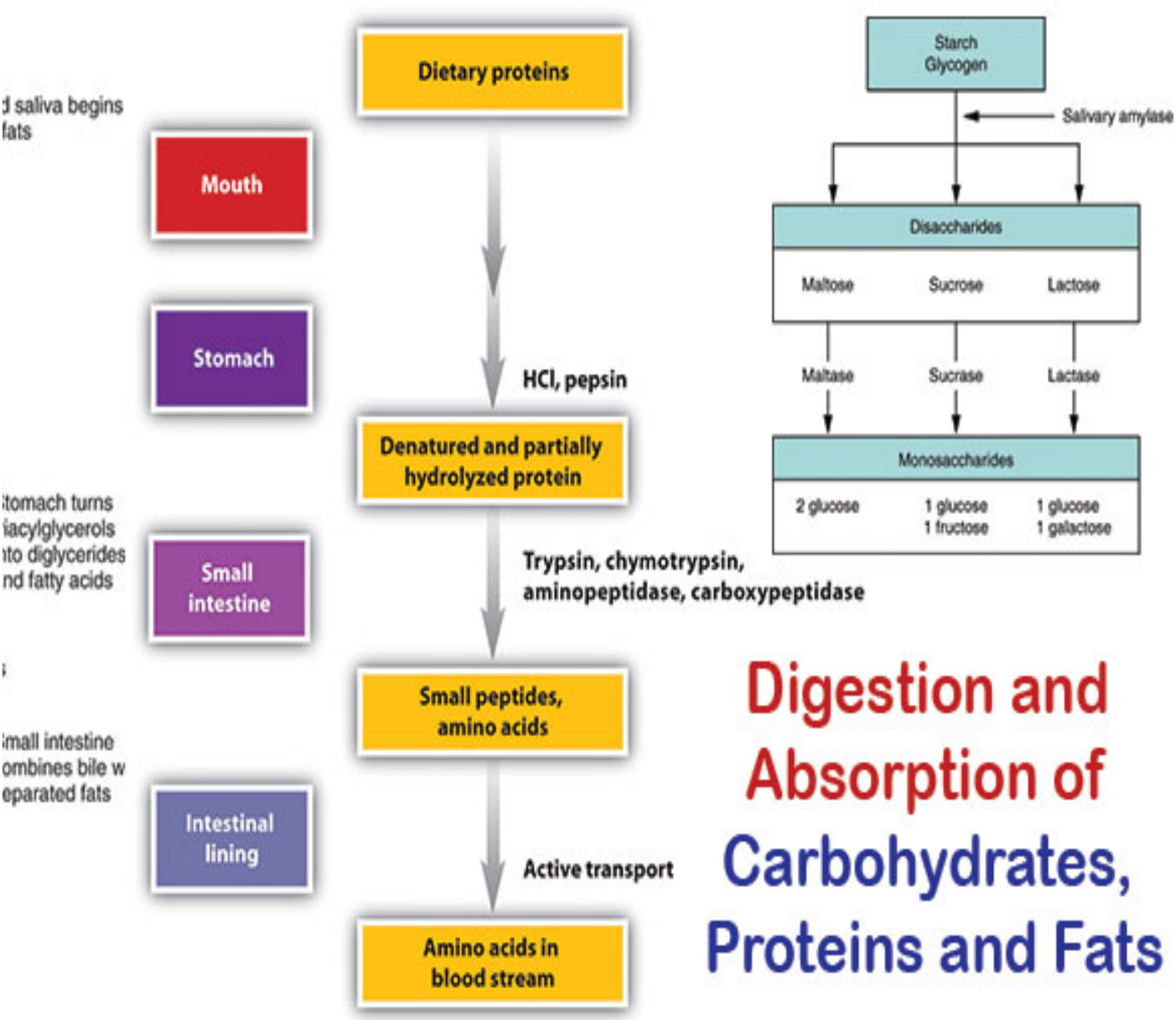
Digestion and Absorption of Carbohydrates, Proteins and Fats

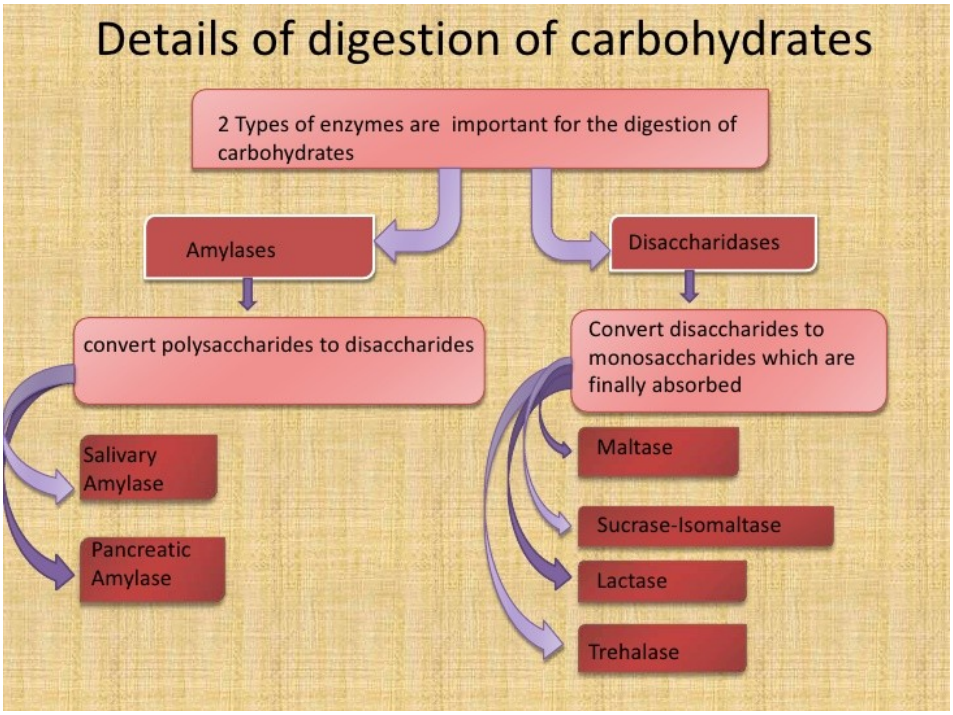
(M.Pal)

- **Carbohydrates**, **fats**, and **proteins** are the major nutrients the body needs for growth, repair, movement and maintaining tissue and organ function.
- These macromolecules are broken down and absorbed into the body at different rates and into specific forms as they travel through the organs in the digestive system.



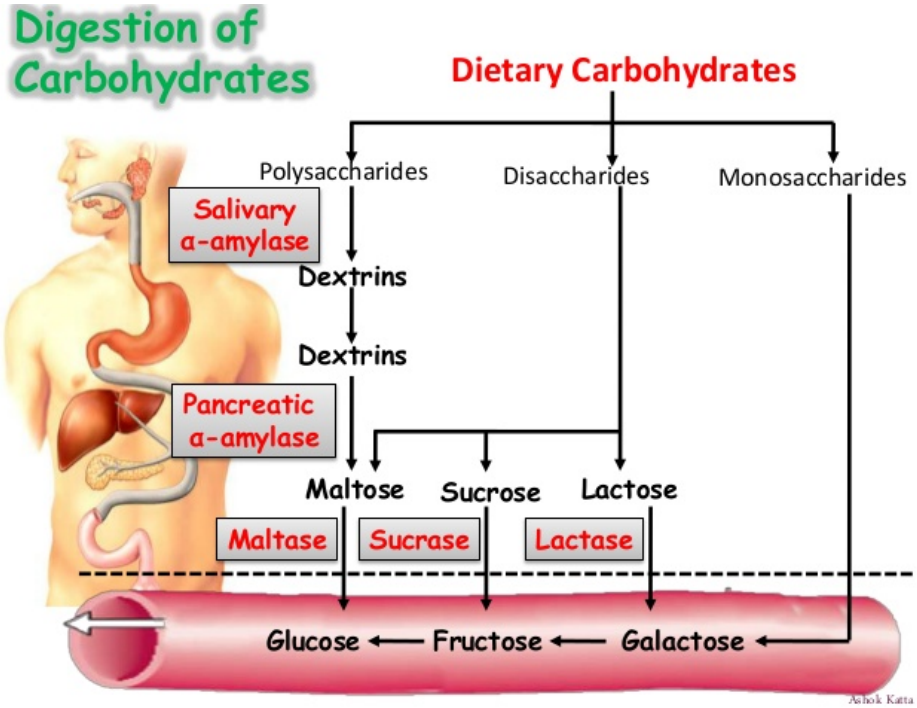
Digestion of carbohydrates

Among carbohydrates, only the monosaccharide forms are absorbed. Hence, all carbohydrates must be digested to glucose, galactose, and fructose for absorption to proceed.



Enzymes Involved

- **a-Amylases** (salivary and pancreatic) hydrolyze 1,4-glycosidic bonds in starch, yielding maltose, maltotriose, and α-limit dextrins.
- **Maltase,** a-dextrinase, and sucrase in the intestinal brush border then hydrolyze the oligosaccharides to glucose.
- **Lactase**, **trehalase**, and **sucrase** degrade their respective disaccharides lactose, trehalose and sucrose to monosaccharides.
    - Lactase degrades lactose to glucose and galactose.
    - Trehalase degrades trehalose to glucose.
    - Sucrase degrades sucrose to glucose and fructose.



Absorption of carbohydrates

1. Glucose and Galactose

- They are transported from the intestinal lumen into the cells by a Na+-dependent co-transport (SGLT 1) in the luminal membrane.
- The sugar is transported “uphill” and Na+ is transported “downhill.”
- They are then transported from cell to blood by facilitated diffusion (GLUT 2).
- The Na+–K+ pump in the basolateral membrane keeps the intracellular [Na+] low, thus maintaining the Na+ gradient across the luminal membrane.

2. Fructose

- Fructose is transported exclusively by facilitated diffusion; therefore, it cannot be absorbed against a concentration gradient.

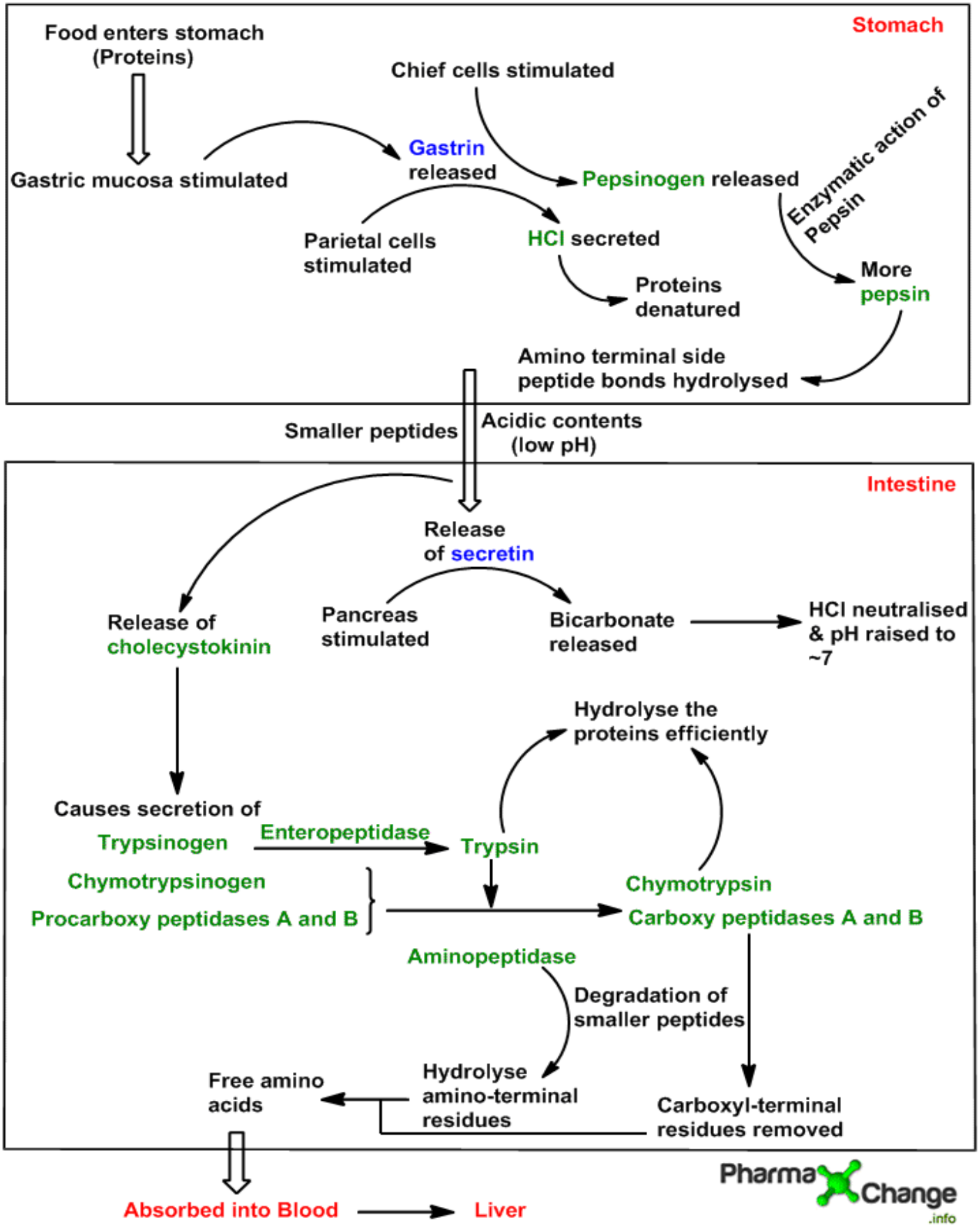
Digestion of proteins

- Dietary proteins are a source of amino acids which are utilized for formation of various cellular substances.
- Mostly, proteins must be broken down into amino acids for absorption. Digestive products of protein can be absorbed as amino acids, dipeptides, and tripeptides
- Both **endopeptidases** enzymes which degrade proteins by hydrolyzing interior peptide bonds and **exopeptidases** enzyme that hydrolyzes one amino acid at a time from the C-terminus of proteins and peptides are involved in the digestion of proteins.
- Digestion takes place in the stomach and the small intestine.

Enzymes Involved

- **Pepsin**
  - Pepsin is secreted in its zymogen form as pepsinogen by the chief cells of the stomach.
  - Pepsinogen is activated to pepsin by gastric H+. The optimum pH for pepsin is between 1 and 3.
  - Pepsin hydrolyzes proteins into peptones and proteoses.
  - When the pH is >5, pepsin is denatured. Thus, in the intestine, as HCO_3^- is secreted in pancreatic fluids, duodenal pH increases and pepsin is inactivated.

- **Pancreatic proteases**
  - The digestion is completed in the small intestine by the action of pancreatic and intestinal juice.
  - The proteases include **trypsin, chymotrypsin, elastase, carboxypeptidase A,** and **carboxypeptidase B.**
  - They are secreted in inactive forms that are activated in the small intestine as follows:
  - Trypsinogen is activated to trypsin by a brush border enzyme, enterokinase.
  - Trypsin then converts chymotrypsinogen, proelastase, and procarboxypeptidase A and B to their active forms.


Stomach
Food enters stomach (Proteins)
Chief cells stimulated
Gastric mucosa stimulated
Gastrin released
Pepsinogen released
Enzymatic action of Pepsin
Parietal cells stimulated
HCl secreted
Proteins denatured
More pepsin
Amino terminal side peptide bonds hydrolysed
Smaller peptides
Acidic contents (low pH)
Intestine
Release of secretin
Release of cholecystokinin
Pancreas stimulated
Bicarbonate released
HCl neutralised & pH raised to ~7
Hydrolyse the proteins efficiently
Causes secretion of
Trypsinogen
Enteropeptidase
Trypsin
Chymotrypsinogen
Procarboxy peptidases A and B
Chymotrypsin
Carboxy peptidases A and B
Aminopeptidase
Degradation of smaller peptides
Free amino acids
Hydrolyse amino-terminal residues
Carboxyl-terminal residues removed
Absorbed into Blood
Liver
PharmaChange.info

Absorption of Proteins

1. Free amino acids

- Na+-dependent amino acid cotransport occurs in the luminal membrane. It is analogous
- to the cotransporter for glucose and galactose.
- The amino acids are then transported from cell to blood by facilitated diffusion.
- There are four separate carriers for neutral, acidic, basic, and imino amino acids, respectively.

2. Dipeptides and tripeptides

- They are absorbed faster than free amino acids.
- H+-dependent cotransport of dipeptides and tripeptides also occurs in the luminal membrane.
- After the dipeptides and tripeptides are transported into the intestinal cells, cytoplasmic peptidases hydrolyze them to amino acids.
- The amino acids are then transported from cell to blood by facilitated diffusion.

Digestion of Fats

- Fats not being soluble in water by their nature are both difficult to digest and absorb. They do not mix with the stomach or intestinal contents.
- Lipids include triglycerides, phospholipids, cholesterol, steroids, and fat-soluble vitamins.
- The first step in lipid digestion is emulsification, which is the transformation of large lipid droplets into much smaller droplets.
- The emulsification process increases the surface area of the lipid-exposed to the digestive enzymes by decreasing the droplet size.

Enzymes Involved

1. In the mouth

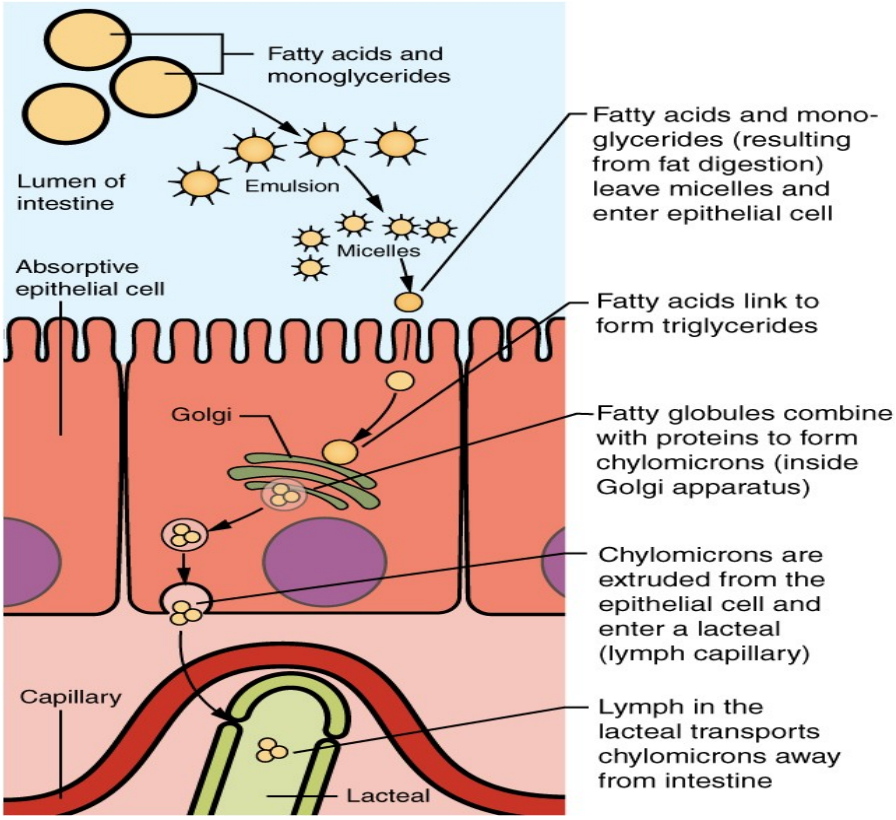
- **Lingual lipases** digest some of the ingested triglycerides to monoglycerides and fatty acids.
- However, most of the ingested lipids are digested in the intestine by pancreatic lipases.

2. Stomach

- In the stomach, mixing breaks lipids into droplets to increase the surface area for digestion by pancreatic enzymes.

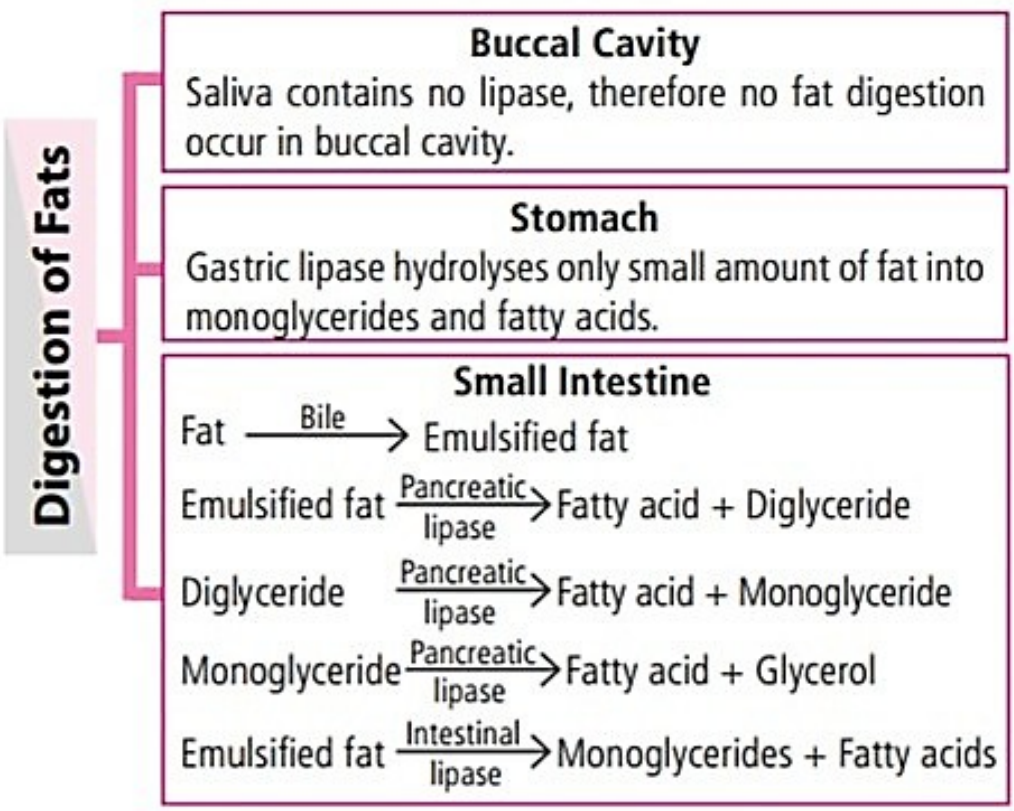
3. Small intestine

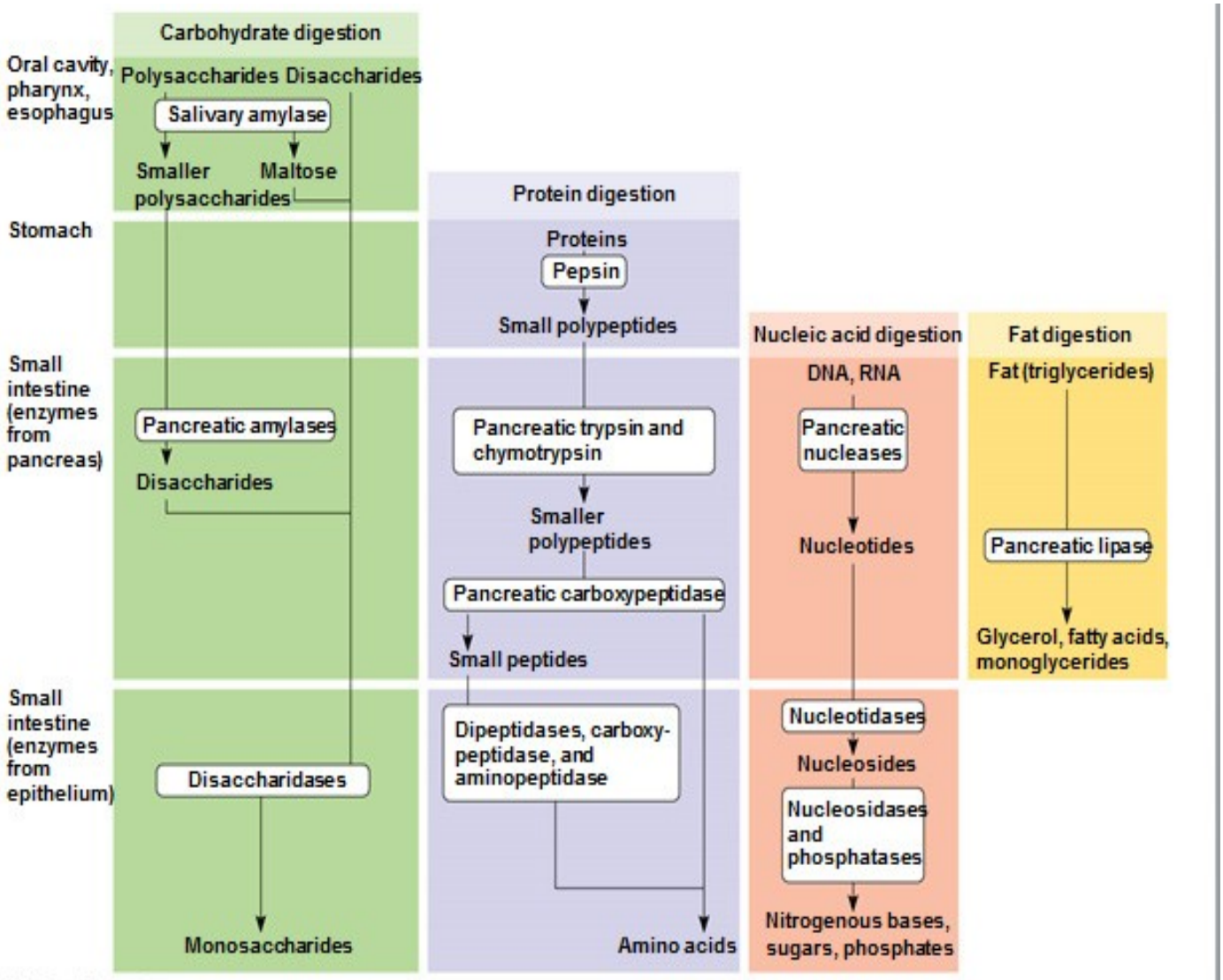
- **Bile acids** emulsify lipids in the small intestine, increasing the surface area for digestion. The hydrophobic products of lipid digestion are solubilized in micelles by bile acids.
- **Pancreatic lipases** hydrolyze lipids to fatty acids, monoglycerides, cholesterol, and lysolecithin. The enzymes are **pancreatic lipase, cholesterol ester hydrolase,** and **phospholipase A2**.

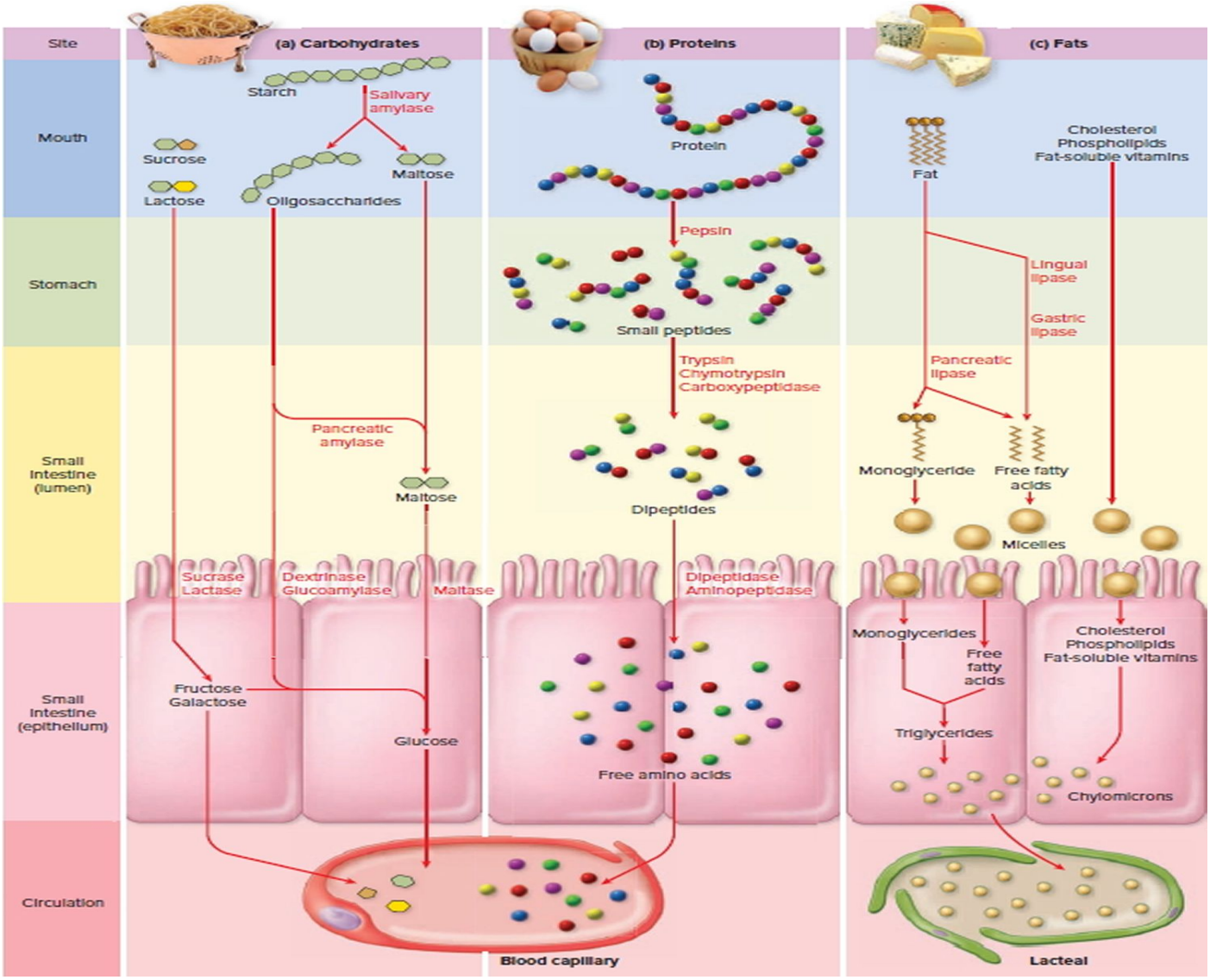


Absorption of Fats

- Micelles bring the products of lipid digestion into contact with the absorptive surface of the intestinal cells.
- Then, fatty acids, monoglycerides, and cholesterol diffuse across the luminal membrane into the cells. Glycerol is hydrophilic and is not contained in the micelles.
- In the intestinal cells, the products of lipid digestion are re-esterified to triglycerides, cholesterol ester, and phospholipids and, with apoproteins, form chylomicrons.
- Chylomicrons are transported out of the intestinal cells by exocytosis.
- Because chylomicrons are too large to enter the capillaries, they are transferred to lymph vessels and are added to the bloodstream via the thoracic duct.







MMMMMMMMMMMMPPPPPPPPPPPPPPP

Digestion Lipids

Digestion is the breakdown of food into its individual nutrients and absorption is the process by which those nutrients travel from the small intestines into the bloodstream. Most of the lipids we consume are in the form of triglycerides. Triglycerides consist of three fatty acids attached to a glycerol backbone as shown in the image to the right. Triglycerides are the "fat" we eat and about 90-95% is absorbed. Triglycerides are also called triacylglycerols (TAGs). We also consume sterols, mostly as cholesterol, and to a small extent phospholipids. About 50% of the cholesterol we consume is absorbed.

Very little lipid digestion take place in the mouth. In the stomach, triglycerides start to be broken apart mechanically and by an enzyme called gastric lipase. When lipids reach the small intestines, bile is released and creates neat packages that allow lipids to be suspended in the watery environment of the intestines (more below). An enzyme called pancreatic lipase is released from the pancreas. Lipase further breaks down triglycerides to monoglycerides and two free fatty acids. A monoglyceride is a single fatty acid attached to the glycerol backbone. Monoglycerides are also called monoacylglycerols (MAGs). In the image to the right, note that the central fatty acid is attached to the glycerol backbone and the two remaining fatty acids are *free*.
A similar process takes place for phospholipids. A phospholipase enzyme breaks down the phospholipid releasing free fatty acids. Most cholesterol (~85%) consumed is in a free form, requiring no further digestion.

The Role of Bile

Bile is made in the liver and stored in the gallbladder. When lipids enter the small intestines, this triggers the release of bile. Take a look at the image to the right. A bile acid has two sides, a hydrophilic side and a hydrophobic side. *Hydro* means water and *phobic* is a strong fear. Hydrophobic essentially means fear of water. In the image, the yellow side on the left is the hydrophobic side. The right side with the green dots is the hydrophilic side, and hydrophillic means water loving. To allow lipids to travel in a watery environment, the hydrophobic side binds to the lipid and surrounds it. The hydrophillic side, the water loving side, is now exposed to the watery environment. The lipid can now easily travel in an aqueous environment.

To better understand how bile acts as an emulsifier and allows lipids to travel in an aqueous environment, think about creating a salad dressing of vinegar and oil. What does it look like? In the image to the right you can see yellow fat droplets, in blue water in the upper left corner. When we initially pour oil into water, we might see some fat droplets, but they eventually combine and the fat floats to the top. This is what would happen in your intestines if bile was not present. In the lower image, you can see bile surrounding the fat droplets. With its water-loving exterior, it allows fat to be dispersed throughout the fluid environment. Bile aids the digestive process by making it easier for enzymes to digest the fat, but is necessary for lipid absorption. After bile is absorbed and utilized, it can be recycled by the body and reused.

Lipid Absorption

Short chain fatty acids, glycerol and some longer chain polyunsaturated fatty acids do not require bile for uptake into the intestinal cell and transport in the bloodstream to the liver. Saturated fats are hydrophobic and therefore they require bile for transport. Polyunsaturated fatty acids, due to their structure, are less hydrophobic and therefore better able to combine with water and be absorbed unassisted. Longer chain fatty acids, saturated and monounsaturated fatty acids, fat soluble vitamins and cholesterol require bile for absorption.

Once fatty acids are brought into the intestinal cell, they are bound to glycerol to form triglycerides. Then, they are packaged into chylomicrons with proteins, other lipids and fat soluble vitamins are released into the lymphatic system. Chylomicrons are too large to enter directly into the capillaries, so they travel in the lymphatic system until they eventually make it into the bloodstream.